THE EFFECTS OF

MEMORY REHEARSAL AND RETENTION

ON PERCEPTUAL LINE JUDGEMENT PERFORMANCE

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By

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Joseph T. Riegler ENTITLED The Effects of Memory Rehearsal and Retention on Perceptual Line Judgement Performance BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Arts.

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ABSTRACT

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Thirty-two subjects performed a perceptual line judgement task at two levels of difficulty during the retention interval of a letter memory task, which also varied in difficulty. One half of the subjects were instructed to stop rehearsal of the memory letters prior to making the line judgement, while the other subjects were given no instructions to stop rehearsal. Line judgement reaction times, memory reaction times and percent error on the memory task were analysed for single and dual task conditions. The results indicated that an increase in memory task difficulty produced an increase in line judgement reaction time, but only for the group given no instructions to stop rehearsal of the memory letters, and only with the easier line judgement task. Neither group displayed an effect of memory load on line judgement reaction time in the more difficult condition. This was attributed to a ceiling effect. Performance on the memory task was equivalent for the two groups. The results were interpreted as supporting a multiple resources framework that views central processing as consisting of span memory

and active working memory. In this framework, perceptual encoding shares a common resource with active working memory, and span memory relies on a separate resource.

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INTRODUCTION

Unitary Capacity vs. Multiple Resource Models

Human operators of complex modern systems often encounter situations where successful task completion is dependent upon their ability to perform two or more activities simultaneously. Even a task as simple as driving a car requires that the driver attend to the surrounding environment while at the same time operate the steering wheel. An understanding of the mental and physical limitations of the human operator is an essential part of system design to ensure safe and efficient performance.

The limitations on the human information processing system that arise when two tasks must be performed concurrently have been explored extensively in the current attention literature (e.g., Kantowitz & Knight, 1974, 1976; Navon & Gopher, 1979; Wickens, 1980,1984). One theoretical framework used to explain dual task performance is the single capacity or resource model of attention. Single capacity models view the human operator as possessing one undifferentiated capacity or pool with a limited supply of resources upon which all processes place demands (e.g., Moray, 1967; Kerr, 1973; Keele, 1973). The term resource refers to a commodity utilized by this pool (Wickens,

1980,1984), and will be used synonymously with capacity for the purposes of the present research. Recent single capacity models (e.g., Moray, 1967) also assume that resources are variable and can be allocated among concurrent activities with considerable freedom. Performance decrements that arise in dual task situations are interpreted by single capacity frameworks as the demand for resources exceeding an upper limit. Several recent reviews of the data from various timesharing investigations have argued against the notion of a single capacity citing several inconsistencies in current data with the predictions of a single capacity framework (Wickens, 1980,1984; Hawkins & Ketchum, 1982). These reviews outline several phenomena of dual task studies that are difficult to explain within a single resource model. The first of these, perfect timesharing (Wickens, 1980), occurs when two tasks are carried out simultaneously with the same level of performance being maintained as when performed alone. For example, Allport, Antonis, and Reynolds (1972) demonstrated perfect timesharing in an experiment where skilled piano players were able to sight read new music while shadowing prose presented at a rate of 150 words per minute as well as they could perform either task alone.

Wickens (1976) also demonstrated perfect timesharing in a dual task situation where a manual tracking task was performed concurrently with auditory signal detection and a

constant force application task. The conditions in which auditory signal detection and force application were combined showed little evidence of a timesharing decrement. The other two dual task combinations (tracking with force application; tracking with auditory detection) resulted in differing amounts of interference. The force application task, although rated easier than the auditory detection task, interfered with manual tracking more than the detection task. This phenomenon of "difficulty and structure uncoupling", where the easier of two tasks interferes significantly more with a third task is another line of evidence cited by Wickens (1980) against a unitary capacity model.

Another phenomenon which is inconsistent with a single capacity notion is difficulty insensitivity (Wickens, 1980; Kantowitz & Knight, 1976). Difficulty insensitivity occurs when increases in the difficulty of one task fail to influence the performance of a concurrently performed task. Kantowitz and Knight (1976) demonstrated difficulty insensitivity in a dual task investigation that required simultaneous performance of a self-paced tapping task and four variations of an auditory digit naming task. The difficulty of the tapping task was manipulated by increasing or decreasing target width. The results failed to show an overall interaction of tapping difficulty and digit naming task complexity. This result is difficult to

interpret within a single capacity model since increasing demands in one task do not affect performance in the concurrent task.

The analysis of dual task conditions found no main effects of tapping information transmitted in bits per second. Although an effect of tapping difficulty on digit naming was found when the easiest digit naming condition was deleted from the analysis, increasing digit task complexity failed to affect the amount of tapping information transmitted. Again these results argue against a model that posits all operations depending on one common resource since tapping performance appears to be insensitive to increases in the difficulty of the digit naming task.

An additional line of evidence aimed against a single capacity model are structural alteration effects (Wickens, 1980 1984). This refers to instances where changing the processing mode of a task while holding its demand for resources constant results in an alteration in the amount of interference it has on a concurrent task. Wickens (1980) demonstrated structure alteration effects when changing the input (visual or auditory) and output (manual or speech) modalities of a digit processing task resulted in differing amounts of decrements in concurrent tracking task performance. More interference was evident when common modalities were shared between the tracking and

digit processing tasks. Both Wickens (1980) and Hawkins and Ketchum (1980) argue that the single limited capacity model cannot adequately account for the above mentioned timesharing results unless one assumes that the tasks were highly automated. This appears unlikely in the Allport et al. (1972) study since subjects sight read new music while engaging in unrehearsed shadowing of prose with only thirty minutes of timesharing practice. The difficulty insensitivity results of Kantowitz and Knight also can be explained by a single capacity model only if one assumes that the required digit transformations were data limited (Norman & Bobrow, 1975), where further resources invested could no longer benefit performance. However, significant main effects of digit naming complexity were obtained indicating that the various manipulations required additional resources. It is unlikely that four easy or data limited versions of the task would have resulted in main effects.

An alternative theoretical framework proposed by several authors (e.g., Gopher & Sanders, 1984; Navon & Gopher, 1979; Wickens, 1980,1984) to account for timesharing efficiency views the operator as possessing multiple resources. Multiple resource theory explains the information processing system in terms of various resources being associated with different processing structures. According to Wickens (1980,1984) these processing

structures may be defined by codes of processing and response (spatial/manual, verbal/vocal), modalities of processing (auditory vs. visual), and stages of processing (perceptual/central vs. response). This multidimensional framework predicts that the amount of interference between two concurrently performed operations is determined by the extent to which they share common resources. According to this model, a task whose demands are primarily motor or response related will be less efficiently timeshared with another manual task than with a cognitive or perceptual task. In the latter case minimal overlap in the demand for resources is present so concurrent performance can be carried out with minimal interference. Multiple resource theory also predicts that manipulations in the difficulty of one task will affect only the performance of that task if a concurrent task relies on a different resource for performance.

Multiple Resource Dimensions

A critical issue in multiple resource theories is determining the dimensions within the processing system that actually define separate resources. The present research is aimed at exploring the Wickens (1980,1984) proposition that different stages of processing define separate resources. According to the Wickens framework, the stages of perceptual encoding and central processing

demand a common resource while motor related activities depend on a separate resource. The evidence for the distinction of motor related resources from cognitive resources is supported by various timesharing results (see Wickens 1980 for complete review). The evidence supporting the commonality of perceptual and central processing resources, which will be outlined in detail later, is somewhat less conclusive. The evidence which supports each of these assertions will be reviewed in the following sections.

Perceptual/Central Processing vs. Response

Support for the notion of processing stages defining separate resource pools has been found in several investigations which are outlined in the Wickens (1980) review. In one of these, Roediger, Kantowitz and Knight (1977), the issue of a limited capacity was investigated by requiring subjects to perform two versions of a tapping task which varied in difficulty and a backward counting task on separate trials while simultaneously holding five words in memory. The results showed that of the three interpolated activities performed during the retention interval, only the backward counting condition had a significant detrimental effect on recall of the memory task. Increases in both difficulty and rate of the tapping task failed to produce decrements in memory performance.

These results are consistent with the multiple resource model of stage defined resources, since difficulty manipulations of a task whose demands are response related failed to affect the performance of a task whose demands are more cognitive in nature.

Other results that support this framework of stages defining separate resource pools were reported by Gopher, Navon and Brickner (1982). In this study, a two dimensional pursuit tracking task was paired with a letter typing task. The difficulty of the letter typing task was varied either by increasing memory set size (cognitive load) or by increasing motor related factors by requiring difficult motor transitions on some trials. The results showed that the two types of letter typing manipulations had differential effects on performance of the primary tracking task. Increased motor difficulty produced larger decrements than increased cognitive difficulty in dual task conditions. However, in single task performance, the cognitive manipulation of the letter typing task affected performance more than motor demand manipulations. The authors argued that these results support a model in which the letter typing tasks demanded resources from the same structure as the tracking task but in differing amounts, as well as drawing from a cognitive-related resource pool.

Additional evidence supporting the distinction between perceptual/central processing and motor output was found in

three investigations of system monitoring while concurrently performing other activities, (Wickens & Kessel, 1979, 1980; Micalizzi & Wickens, 1981). Wickens and Kessel (1979) required subjects to monitor and detect system failures of a dynamic pursuit tracking display in both an autopilot and a manual control mode, while concurrently performing a subcritical tracking (Jex & Clement, 1979) task. The difficulty of the subcritical tracking task was manipulated to form two levels of difficulty. Failure detection performance, measured in terms of latency and accuracy of response, was reduced when concurrently performed with tracking for each mode. However, the requirement to manually control the system and detect failures did not result in significant performance decrements as compared to situations where subjects only monitored the system for failures. Wickens and Kessel (1979) explain this manual control mode stability by drawing a distinction between "perceptual/ decision making" processes and response processes. These two processes are seen as drawing capacity from different structural pools that are not mutually available. Therefore according to this framework, it is not expected that the additional requirement of having to manually control the system should result in poorer detetction performance since each process has a separate supply of resources.

Wickens and Kessel (1980) again required subjects to

manually control (MA) or monitor an autopilot (AU) controlling a dynamic pursuit tracking system while simultaneously performing a Jex (1967) critical tracking task or an arithmetic-memory task. The critical tracking task only had adverse effects on the MA mode of the primary task whereas the arithmetic-memory task only disrupted AU detection. Assuming that the arithmetic task draws primarily on perceptual/central processing resources, these results are consistent with the stage-defined multiple resources outlined by Wickens.

Micalizzi and Wickens (1980) also utilized the autopilot controlled system in a dual task investigation. Subjects in this study detected failures introduced into a single axis pursuit tracking display while concurrently performing a Sternberg memory task. The Sternberg task required subjects to hold a stimulus set of random dot patterns in memory and respond negatively or positively to probes, depending upon whether they were a member of the original set or not. The Sternberg task was varied in difficulty at both the perceptual stage, by degrading stimulus quality, and at the response stage, by requiring two buttons to be pressed in succession instead of one. The results showed that the increase in response demands of the Sternberg failed to disrupt failure detection performance, but increases in perceptual difficulty resulted in decrements in failure detection. These results

further support the notion of perceptual encoding and response related processes relying on separate resources, since manipulation at one stage of processing failed to affect performance of a task requiring another stage.

Additional evidence that supports this framework of stage-specific processing resources was reported in a study by Israel, Chesney, Wickens, and Donchin (1980). In this investigation subjects concurrently counted tones delivered binaurally and performed a one dimensional tracking task in which target bandwidth increased at set intervals on some trials and decreased on others. The P300 component of the event related brain potentials (ERP's) were recorded for all conditions of single and dual task performance. The P300 component was chosen since it has been shown to be highly sensitive to embedded stimuli as well as an indicant of the demand for cognitive resources, (Israel, Wickens, Chesney & Donchin, 1980). The ERP amplitude in response to tone counting diminished immediately upon introduction of the tracking task, and variations in tracking bandwidth failed to reduce the amplitude further. The inability of increasing tracking difficulty to further affect the evoked brain potential elicited in the tone counting task can be interpreted by assuming that different resources were being used for each task.

Wickens, Sandry, and Vidulich (1983) investigated resource competition between tasks when modalities of

input, central processing and output were manipulated. Subjects time-shared a one-dimensional compensatory tracking task with a memory search reaction time task. The memory search task was performed with all four input/output combinations of auditory, visual, manual, and speech modes. Performance on the tracking task suffered most when a manual response for the memory task was required. The other dual task conditions resulted in only minimal interference. Therefore, only increases in the competition for motor or response-related resources during concurrent performance disrupted the tracking task, which primarily relies on motor demands. Again, separate resources appear to be available for operations that are carried out at different stages of processing.

Perceptual/Central Processing Commonality

The literature reviewed thus far lends support to the notion that response related functions demand resources from a separate pool of resources than perceptual/central processing functions. The notion that perceptual encoding and central processing stages draw from the same limited capacity has been supported by several studies in the information processing literature. Although these studies provide general support for the commonality of perceptual encoding and central processing resources, their results suggest that there are some critical variables that appear

to affect the magnitude of perceptual/central processing interference. The studies whose results support the perceptual/central processing resource commonality position will be reviewed in this section. The majority of these have examined the effects of performing various perceptual tasks during the retention interval of a memory task, (Friedman, Polson, Gaskill, & Dafoe, 1982; Greenberg, 1977; Reitman, 1971, 1974; Shulman & Greenberg, 1971).

Shulman and Greenberg (1971), in an investigation of the effects of information storage on performance of a perceptual task, found that when subjects divided their attention between a memory and a line judgement task, reaction time decrements occurred in the perceptual judgements of line length. The line judgement task was performed immediately after the offset of a list of 2,4,6,or 8 letters which subjects were required to retain for recall. Reaction time to the line judgement task increased as a function of memory load. Shulman and Greenberg argued that the results supported a single limited capacity framework, where two distinct processes cannot be carried out simultaneously once an upper capacity limit is exceeded. In a follow-up study Shulman, Greenberg, and Martin (1971) delayed the onset of the perceptual task for time intervals of 2, 5, and 8 seconds after offset of the memory stimuli. Again, as memory load increased to nine items, reaction times to the perceptual

judgements were slower. However, at increasing delays of onset of the line task the effect of memory load on line judgement speed was less pronounced. The effect of delay appeared to be greater for memory loads of six and nine items despite an insignificant memory load x delay interaction. Since the magnitude of the decrement in the perceptual task appeared to decrease over time, the authors suggested that short term load might affect perception, whereas long term load may not.

Greenberg (1977) again found that perceptual processing of a recognition task was affected by a concurrent memory load. In this experiment both pronounceable and non-pronounceable shapes were used as perceptual stimuli. The pronounceable stimuli consisted of line drawings of letters while nonpronounceable stimuuli were random line drawings These stimuli were either similar or dissimilar on both a visual and acoustic basis to the stimuli in the memory set, which consisted of either words or geometric forms. The perceptual recognition task, performed during the retention interval of the memory task, was disrupted by each version of the concurrent memory task. The effect was magnified when the stimuli used in each task were visually similar. These results were interpreted as supporting a framework that views memory and perceptual recognition as being dependent on a single limited capacity when the stimuli from each task are

visually confusable.

Reitman (1971, 1974) also explored the issue of interference with information storage when a perceptual task was concurrently performed with a memory load. Her 1971 results showed that tonal detection performed during the retention interval of a three word memory load produced no interference or loss with time of items in short term memory. Reitman (1974) failed to replicate these findings using a larger memory load (5 items) and instructions to rehearse during the tonal detection task on some trials and not to rehearse on others. In this study it was found that rehearsal relative to the nonrhearsal condition disrupted both detection accuracy and reaction time. Apparently the results of the 1971 study were due to a performance ceiling effect, since there was considerably more forgetting with the increased memory load in the 1974 study.

Watkins, Watkins, Craik, and Mazuryk (1973) also found results that provide some qualified support to the single perceptual/central processing capacity hypothesis. In this study, tone shadowing, silent rehearsal of a memory list, or listening to tones were performed during four retention intervals ranging from three to twenty seconds. Decreases in percent recall over the four retention intervals were significant only for the tone shadowing condition which involved pressing a sequence of four piano keys that corresponded with tones presented during the retention

interval of a verbal memory task. The other two conditions showed no evidence of decline in memory performance.

More recent evidence of concurrent perceptual demands resulting in memory performance decrements relative to single task trials was found by Friedman, Polson, Gaskill, and Dafoe (1982). In this study the requirement to perform same-different classifications of three letter nonsense syllables during the retention interval of a memory load task significantly disrupted recall as compared to single task conditions.

Data from this study also revealed that the types of classifications required in the perceptual judgement task had different effects on memory task performance. When subjects were required to make their judgements based on the physical structure of the two nonsense syllables, memory decrements were less severe compared to the conditions where the judgements were based upon whether the pair had the same name. This difference in the interference of perceptual processing demands at a physical identity versus a name level with a concurrent central processing load suggests that the commonality of perceptual and central processing resources may be dependent on the nature of the tasks involved in the timesharing situation. In the Friedman et al. study name judgements may have interfered with the memory task more than physical judgements since they involved a central processing

component shared by the memory task.

Dual Short Term Memory Hypothesis

In summary, the hypothesis that central processing and perceptual encoding rely on a common resource is generally supported by the results of studies that show performance decrements in perceptual judgement tasks performed during the retention interval of a short term memory task. Although generally supportive, the results do indicate that certain circumstances, such as the degree of similarity between the perceptual and memory stimuli (Greenberg,1977) and the temporal separation between the memory and perceptual tasks (Shulman et al. 1971) affect the degree of perceptual/central processing interference.

The presence of a rehearsal period or delay prior to perceptual task presentation following a memory load has recently been investigated in a series of experiments by Klapp, Marshburn, and Lester (1983). The results of these studies have been interpreted as suggesting that the short term memory function associated with central processing resources may in fact represent two distinct processes. The variant of this dual short term memory system approach which is critical to the present research suggests that short term memory involves an active or working memory which is the site of ongoing cognitive activities such as the manipulation of words or symbols as well as a span memory which involves the retention or temporary storage of

items independent of active processing.

A similar type of view has been outlined by Hitch and Baddeley,(1976). These researchers argue that working memory is a general executive system with a limited capacity for processing information and is only one component of short term memory.

This notion of a distinction between "working memory" and span memory has been investigated experimentally by inserting a delay between the offset of a memory task and the onset of a concurrent task to allow for the consolidation of the memory items. Klapp et al. (1983) conducted a series of experiments designed to test the notion of separate memory systems and found that when an initial rehearsal period was provided immediately following a list of memory items, a second information processing task performed during the retention interval was unaffected by the presence of the memory load. One experiment of the Klapp et al. (1983) series employed the concurrent retention and discrimination task paradigm utilizing two memory loads, six and nine items, and a numerical reasoning task. The reasoning task required subjects to make true-false judgements regardng the relationship of two numbers (e.g. "5>7"). Subsequent to receiving a memory load of zero, six, or nine letters the subjects in the delay-before-task condition were given a five second blank period during which they were to rehearse the memory

letters. Following this period the message "STOP REHEARSAL" was displayed for 500 msec. After an additional one second, the numerical task was presented. Subjects attempted to recall the memory items after responding to the numerical task. Subjects in the delay-after-task condition received the same memory items which were immediately followed by the numerical task. After the subject responded to the judgement task, a delay of 6.5 seconds was given before the signal to recall the memory letters. The design also included a no task condition during which the memory load presentation was followed by a five second delay, the words "STOP REHEARSAL" and then a nine second delay prior to the signal to recall the memory items.

The results of the analysis of the numerical reasoning task data showed that the reaction times for the delay-before-task condition were the same for all short term memory load conditions. For the delay- after-task condition, reaction times to the reasoning task were significantly longer under the six and nine item memory loads than for the delay before task condition. This difference in the two delay conditions was confirmed by a significant delay x memory load interaction. This interaction was interpreted as indicating that the process of memory consolidation early in the retention interval interfered with the numerical reasoning task. When a delay

before the reasoning task was provided, no such interference occurred between retention of the memory items and the numerical task. This finding suggests that short term memory consists of at least two separate processes. One of these processes, consolidation or rehearsal, shares capacity with numerical reasoning while the other is unaffected by it.

In a subsequent experiment, Klapp et al. (1983) examined the effect of a concurrent processing task which placed larger demands on working memory than the numerical task. Subjects in this study performed a modified version of the Sternberg (1969) memory search task during the retention interval of the same memory task used in the experiment just described. The modified Sternberg task required subjects to indicate whether or not a target stimulus was a member of a memory set. A memory set of either two or four numbers was present when the target appeared but the spacing of the two was such that simultaneous foveal vision for both was not possible. The task resembled a standard visual scanning task, since it required the subject to search the memory set to locate the target. The procedure was similar to that in the previous experiment. Subjects performed the concurrent memory task during the retention interval of zero, three, and six letter memory loads. Again, the reaction time to the concurrent task was insensitive to memory load for the

delay-before-task condition.

The last experiment in the Klapp et al. (1983) series supported the working memory vs. span memory interpretation by showing that letter recall was in fact a function of short term and not long term memory. It was important to demonstrate that long term memory was not involved since it could be argued that the portion of short term memory in the present interpretation identified as span memory was in fact long term memory. In this experiment the immediate recall of three digits embedded in the retention interval of the same letter memory task resulted in the disruption of letter memory even though an initial rehearsal period was provided. If long term memory storage accounted for the results found in the previous two experiments, this lack of interference would also be predicted for this experiment.

In a subsequent study, Klapp and Philipoff (1983) found that subjects could successfully retain six letters while performing a concurrent missing digit task. The procedure of this study also included a brief rehearsal period following an input of six letters. During the retention interval, subjects performed one of two embedded missing digit tasks. In both of the embedded missing digit tasks subjects were sequentially presented eight digits. In the "missing digit" task, the subjects responded by indicating which of the nine non-zero digits had not been presented. In the "probe" task, a digit appeared and the

subjects were required to indicate which digit had appeared after the probe in the original sequence. The only dual task decrement observed resulted when the probe task was performed concurrently with the letter memory task. The missing digit task, which did not require subjects to retain ordered information, was not disrupted by the concurrent memory load task.

Therefore,the results reported by Klapp and his colleagues appear to indicate that the retention of ordered information may be a critical factor in the proposed division of short term memory into working and span memory. More specifically, their results suggest that when a task embedded within a memory task requires retention of ordered information, interference will result even when a rehearsal period is provided following the memory items. Therefore,the proposed portion of short term memory defined as span memory appears to be disrupted by retention of ordered information but not active processing.

Sanchez, Shea, and Wessel (1985) also used the two concurrent memory tasks paradigm with a brief rehearsal period separating each task. The embedded memory task was a Sternberg task with a memory set size of seven digits. The embedded task was performed during the retention interval of a memory task which involved the oral recall of six letters. Memory stimuli for each task were presented either both sequentially, both simultaneously, or one

simultaneously and the other sequentially.

The results showed that the embedded memory task was unaffected by either version of the letter memory task when the embedded task stimuli were presented simultaneously. However, sequential presentation of embedded memory task stimuli caused significant decrements relative to single task trials. This interference was mutual and occurred for both the sequential and simultaneous presentations of the letter memory task. This finding is consistent with the previous findings of Klapp et al. (1983) and Klapp and Phillipoff, (1983) in that an embedded memory task was unaffected by a concurrent memory load in instances where the embedded task was presented sequentially and required ordered recall. Although Klapp did not include a simultaneous presentation procedure, the Sanchez et al. (1985) results indicate that this may be an important consideration.

The results of the studies which include a brief rehearsal period prior to concurrent task presentation as part of their procedure provide some evidence against the notion of a single memory system. These findings also have potentially significant implications for the evidence upon which Wickens (1980,1984) based his assertion that central processing and perceptual encoding resources are drawn from a common pool. It is plausible, given the Klapp et al. (1983) and Sanchez et al. (1985) results, that some of the

research supporting the commonality of perceptual and central processing resources reviewed to this point may have reflected competition for working memory resources. According to this view, central processing capacity may be composed of two functions, only one of which (working memory) shares resources with perceptual encoding. A second function involved in retention of ordered information, span memory, may not share the same resource pool as the active memory component.

Aim of Present Research

The purpose of the present study was to re-examine previous research which appears to support the perceptual/central processing commonality position utilizing the Klapp methodology of including a brief rehearsal period prior to embedded task presentation. This investigation was a replication of the Shulman et al. (1971) study, in which subjects performed a perceptual line judgement task during the retention interval of a letter memory task. Unlike the Shulman et al. (1971) design, the present study included one condition where the brief delay between the offset of the memory stimuli and the onset of the line judgement task was followed by the instructions to stop rehearsal. Subjects in the Shulman et al. (1971) study were given no instructions to cease rehearsal.

A condition where subjects are not given any instructions to stop rehearsal prior to line judgement task

presentation was also included. This latter condition is a replication of the Shulman et al. (1971) 5 second delay condition, where a main effect of memory load on line judgement reaction time was found. The design also included single task trials of a sequentially presented letter memory task and a line judgement task performed at two levels of difficulty.

Both a delay-before and delay-after perceptual task presentation condition were incorporated as in Klapp et al. (1983) to investigate the effect of a rehearsal period on line judgement task performance. The absence of a significant interaction between memory load and line judgement task when subjects stop rehearsal would support the position, which views short term memory as being composed of more than one system. However, the finding of a significant memory x line judgement task interaction in the stop rehearsal condition would appear to contradict the dual resource position and support the Wickens (1980,1984) position of a common perceptual/central processing resource.

METHOD

SUBJECTS

Thirty-two Wright State University students served as subjects in the present experiment. Each subject was paid $4.00 per hour for participation. One half of the subjects in each instruction group were males and one half were females. Subjects were between the ages of 20 and 34 years old.

APPARATUS

Memory and perceptual task stimuli were presented on a Panasonic 12-inch black and white video monitor (model no. WV-5410) controlled by a Commodore VIC-20 microcomputer. Memory stimuli were drawn randomly from the letter population (B G F H R L M S K) used by Klapp et al. 1983. Only upper case letters were used. Letters measured 5mm x 5mm and were presented sequentially in groups of three or seven letters. Subjects were seated at a distance of one meter from the monitor.

The perceptual task stimuli consisted of two or four vertical lines. One line was always longer than the other line(s) in the display. The lines were separated by 1 inch and ranged in length from 1.50 in. to 1.75 in. The results of a pilot study demonstrated that the difficulty

levels of each task yielded significantly different results in reaction time and percent error.

Subjects made their responses by depressing one of four horizontally positioned buttons on a keypad for the line judgement task. The buttons were labeled 1Y, 2N, 3, 4 from left to right. For the memory task the same keypad was used but subjects were only required to depress button 1Y for a yes response or 2N for a no response.

EXPERIMENTAL DESIGN

This experiment employed a mixed factor design consisting of three within subjects factors and one between subjects factor. The between subjects factor was rehearsal group. The two levels of this factor included one group that was instructed to stop rehearsal of the memory items prior to performing the line judgement task and a second group that received no such instruction. Each group consisted of sixteen subjects. The experiment consisted of single and dual task conditions. Single task conditions included two levels of memory task difficulty (3 and 7 letters) and two levels of the line judgement task difficulty (2 and 4 lines). The eight dual task conditions were the two memory task levels performed with both levels of the line judgement task with a delay occuring (a) before, or (b) after the line judgement task.

Each subject practiced one block of ten trials under each of the twelve experimental conditions prior to actual

data collection. During data collection each subject performed one block of twelve trials under each dual task condition and two blocks under each single task condition. Therefore each subject performed a total of sixteen blocks during data collection, eight single and eight dual task.

The order of experimental conditions was determined using separate four level Latin squares for subjects, the eight dual task conditions, and the four single task conditions. The order of the two dual task delay conditions, before and after line judgement task, were counterbalanced such that one half of the subjects performed the delay before task condition first, while the other half performed the delay after task conditions first. These orders were repeated for each of the two groups.

The order of the twelve experimental conditions followed an ABBA counterbalancing design. For half of the subjects in each group a set of two dual task blocks preceded two sets of two single task blocks, which were followed by two dual task blocks. For the remaining half a set of two single task blocks preceded two sets of two dual task blocks, which were followed by two single task blocks.

PROCEDURE

Single task trials: Each of the two stop rehearsal group dual task conditions, delay-before and delay-after, had a separate single task memory control condition. The no instruction group consisted of only one single task memory

control condition since a delay relative to the stop rehearsal cue was irrelevant for this group. All single task memory trials began with the simultaneous presentation of a warning tone and a fixation point for a duration of 750 msec. After a 750 msec blank interval, the consonant string was then presented at a rate of one letter per second. After the last letter was presented, a ten and a half second blank retention interval followed. This interval was selected to equate single and dual task trials. Following the blank retention interval, a fixation point consisting of two asterisks was displayed for 750 msec. A pair of probe letters appeared one second later vertically positioned in the same location for a duration of three seconds. For the stop rehearsal group a "STOP REHEARSAL" signal preceded the fixation point and probe letters by 3.5 seconds in the delay before condition and by 8.5 seconds in the delay after condition. Each subject made his/her response by depressing the button labeled "1, Y" if the letters appeared in the original list in the order displayed. Subjects depressed the button labeled "2, N" if the letters were not in the order shown in the original list. Therefore the task required the retention of ordered information. For each block the probe required a positive response on one half of the trials. The probe stimuli always appeared in the original memory set. The next trial began as soon as the three second

probe duration expired. Subjects were instructed to use their preferred hand to make responses. Any responses made after the three second probe duration were scored as incorrect.

Single task line judgement trials began with a warning tone and asterisk for a 750 msec duration. After a blank 750 msec interval two or four vertical lines were presented for a duration of two seconds. Subjects depressed the button on the keypad that corresponded with the longest line on the screen. For trials consisting of two lines the same two buttons used in the memory task were used. All four buttons were used for those trials consisting of four lines. In each case subjects responded using their preferred hand only.

Dual task trials: The four dual task conditions are displayed in Table 1. All dual task trials began with the presentation of the consonant string as in single task trials. For the two delay-before perceptual task conditions, a 7 second blank delay followed the memory letters. After this, the group receiving instructions to stop rehearsal saw the words "STOP REHEARSAL" appear for 750 msec along with a warning tone. After a 750 msec blank interval, the vertical line judgement task was displayed for a two second duration. For the group receiving no instructions to stop rehearsal a row of four asterisks presented simultaneously with a warning tone replaced the

STOP REHEARSAL - DELAY BEFORE

*	DELAY	MEMORY LETTERS	DELAY	STOP REHEARSAL	DELAY	LINE DISPLAY	* *	DELAY	MEMORY PROBE
750 MSEC	750 MSEC	3,7 SEC	7 SEC	750 MSEC	750 MSEC	2 SEC	750 MSEC	1 SEC	3 SEC

STOP REHEARSAL - DELAY AFTER

*	DELAY	MEMORY LETTERS	DELAY	STOP REHEARSAL	DELAY	LINE DISPLAY	DELAY	* *	DELAY	MEMORY PROBE
750 MSEC	750 MSEC	3,7 SEC	2 SEC	750 MSEC	750 MSEC	2 SEC	5 SEC	750 MSEC	1 SEC	3 SEC

NO INSTRUCTION - DELAY BEFORE

*	DELAY	MEMORY LETTERS	DELAY	****	LINE DISPLAY	* *	DELAY	MEMORY PROBE
750 MSEC	750 MSEC	3,7 SEC	7 SEC	750 MSEC	2 SEC	750 MSEC	1 SEC	3 SEC

NO INSTRUCTION - DELAY AFTER

*	DELAY	MEMORY LETTERS	DELAY	****	LINE DISPLAY	DELAY	* *	DELAY	MEMORY PROBE
750 MSEC	750 MSEC	3,7 SEC	2 SEC	750 MSEC	2 SEC	5 SEC	750 MSEC	1 SEC	3 SEC

Table 1. Dual task procedures for each instruction group

"STOP REHEARSAL" message. Due to a timing error in the dual task trials the line judgement task in the no instruction group immediately followed the four asterisks warning cue whereas a 750 msec. blank delay preceded the line judgement task in the stop rehearsal group. This absence of a delay prior to the line judgement task in the no instruction group was investigated in a follow up study, (see Appendix A) which involved sixteen subjects and replicated the procedure outlined for the delay-after condition. The design included a condition with the 750 msec. delay that was present in this study and also a condition involving no delay prior to the line judgement task. The results indicated that line judgement reaction time and errors did not differ between the two delay conditions. Therefore, the absence of a 750 msec. delay in the no instruction group was not considered to be a factor that affected line judgement reaction time.

Subjects were instructed to respond to the lines in the same manner as in single task trials. A fixation point consisting of two vertically positioned asterisks then appeared for 750 msec. with a warning tone. After an additional one second delay the probe letter pair was presented for three seconds. Subjects were instructed to respond to the probe pair in the same manner as single memory task trials. The next trial began immediately following the expiration of the memory probe.

For the delay-after line judgement task conditions, the memory letters were followed by a 2 second blank delay, a 750 msec warning tone and asterisk display, followed by the vertical lines for a two second duration. After a 5 second blank delay, the fixation point for the memory probe appeared for 750 msec. followed by a one second delay and then the probe letters. In the stop rehearsal instruction delay-after task condition the words "stop rehearsal" were presented in place of the asterisk display, along with a 750 msec blank delay, prior to the line judgement task.

Subjects were instructed to emphasize memory task performance during all dual task conditions. The rationale for memory priority instructions was twofold. First, Shulman et al. (1971) and Klapp et al. (1983) instructed subjects to emphasize the memory task. Secondly, any changes in line judgement performance as a function of memory demand may be interpreted as reflecting resource competition rather than tradeoffs caused by shifting priority from one activity to the other. The complete instructional set is provided in Appendix B.

RESULTS

The results of the line judgement and memory dual task trials will be discussed first, followed by the single vs. dual task data analyses. The dual task data analyses are essential when examining resource commonality, since the timesharing efficiency of the two tasks are directly observed. The single vs. dual task analyses are secondary and examine changes in performance that arise with the introduction of a second task. Single to dual task decrement analyses will be critical in assessing the extent to which the memory emphasis instructions were followed.

Dual Task Line Judgement: The errors in the line judgement task were very infrequent, ranging from .52% across all the two line conditions to .75% across the four line conditions. Because they were so few in number, errors were not further analyzed. Subsequent analyses of line judgement data were conducted on mean correct reaction times from a block of twelve trials per condition.

A four way analysis of variance (ANOVA) with the independent variables of instruction group (stop rehearsal vs. no instruction), delay (before vs. after), memory load

(3 vs. 7 letters), and line judgement difficulty, (2 vs. 4 lines) was conducted on the line judgement reaction time means. Line judgement reaction time as a function of memory load, instruction group, and delay is depicted in Figure 1. The ANOVA failed to show a main effect of delay, $F(1,30) < 1$. Likewise, all the interactions involving delay were insignificant. As displayed in Figure 1, the difference between the two delay conditions is minimal for all dual task conditions. Therefore, the locus of the line judgement task within the retention interval of the memory task did not affect line judgement speed. Subsequent analyses of dual task line judgement reaction time data were conducted collapsing across the two levels of delay.

As is obvious from inspection of Figure 1, judgements involving the two line condition were generally more rapid than those involving four lines. The analysis confirmed this trend and revealed a main effect of lines, $F(1,30) = 170.08$, $p < .0001$. This result was expected and indicates that the difficulty manipulation of two vs. four lines was effective. The analysis revealed no effect of group, $F(1,30) < 1$. indicating that line judgement performance was equivalent for both the no instruction and stop rehearsal groups.

A main effect of memory load on line judgement reaction time was found, $F(1,30) = 10.76$, $p < .002$. Figure

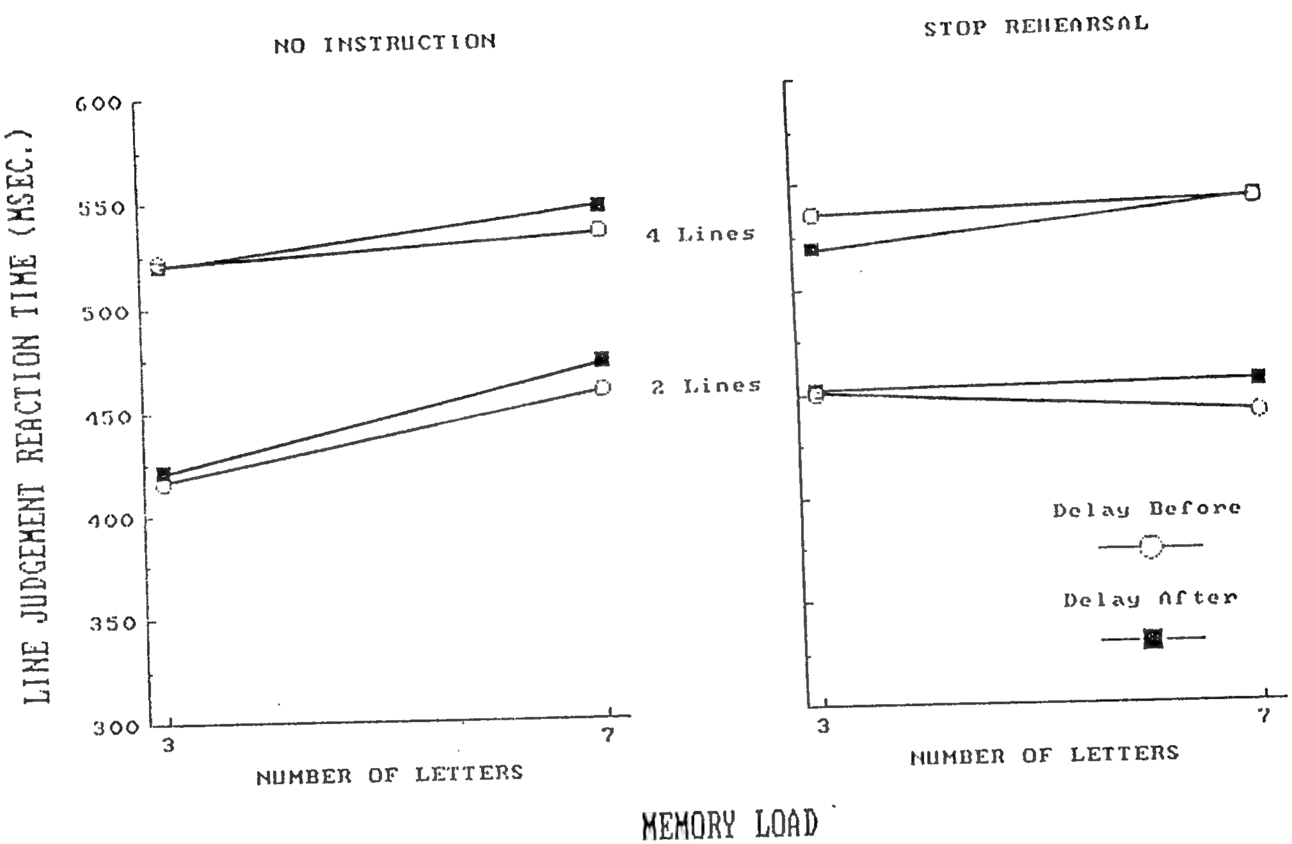

Figure 1. Dual task line judgement reaction time as a function of line judgement difficulty, instruction group, delay and memory load.

1 indicates that the increase of memory load from three to seven letters resulted in an overall increase in the time required to make the line judgements.

The interaction of main interest to the basic hypothesis was the instruction group x memory load x line judgement difficulty interaction, $F(1,30) = 7.64$, $p < .009$. In order to determine the locus of this three-way interaction, a two-way ANOVA involving memory load and line judgement difficulty as independent variables was conducted on each instruction group. The no instruction group analysis revealed a main effect of memory load on line judgement reaction time, $F(1,15) = 9.5$, $p < .007$,and a memory load x line judgement difficulty interaction, $F(1,15) = 4.57$, $p < .05$. This analysis also revealed a main effect of lines, $F(1,15) = 102.45$, $p<.0001$. The analysis of the stop rehearsal group revealed a main effect of line judgement difficulty, $F(1,15) = 72.16$, $p < .0001$. However no main effect of memory load, $F(1,15) = 1.28$, $p > .05$ nor a memory load x line judgement interaction, $F(1,15) = 3.16$, $p > .05$. was found for the stop rehearsal group. Therefore, as memory load was increased from three to seven letters, the only adverse effect on line judgement reaction time occured in the no instruction group.

As noted above, the no instruction group memory load x line judgement difficulty interaction was significant. This interaction appears to be attributal to a trend for

the effect of memory load to be greater for the two line conditions relative to the four line conditions. In order to investigate this apparent difference between the two and four line conditions in the no instruction group, a t-test for correlated samples was conducted on each level of line judgement difficulty. The purpose of each t-test was to determine if an effect of memory load existed only for the two line condition as Figure 1 appears to indicate. The t-test conducted on the four line data in the no instruction group revealed no significant difference in line judgement reaction time between memory loads of three and seven letters, $t(15) = 1.70$, $p > .05$. The t-test conducted on the two line data revealed a significant difference in line judgement reaction time between memory loads of three and seven letters, $t(15) = 3.54$, $p < .003$. Therefore, increases in memory task difficulty resulted in increased line judgement reaction time for the two line task only. The four line task was insensitive to increased memory demands during dual task performance.

The only other significant interaction in the line judgement dual task data anaylysis was the instruction group x memory load interaction, $F(1,30) = 6.45$, $p < .01$. This instruction group x memory load interaction, evident in Figure 1, is consistent with the pattern of the instruction group x memory load x line judgement difficulty interaction discussed previously. For a complete summary of

the dual task line judgement ANOVA see Table 2.

Memory task analysis: Mean percent error and reaction time to the memory task under dual task conditions are displayed in Figures 2 and 3 respectively. Both memory percent error and reaction time were subjected to separate four-way ANOVAs. The independent variables in each ANOVA were instruction group (no instruction vs. stop rehearsal), memory load (3 vs. 7 letters), delay (before vs. after), and line judgement difficulty (2 vs. 4 lines). The most critical aspects of the memory analyses are the effects of instruction group and memory load, since it is necessary to determine whether or not memory performance was the same for each instruction group. If the stop rehearsal group displayed inferior memory performance relative to the no instruction group, it could be argued that this was a result of terminating the memory task and concentrating on the line judgement task. This would weaken any conclusions drawn from the line judgement analyses and would provide a rationale for equivalent performance in line judgement reaction time under varied memory load conditions for the stop rehearsal group.

The ANOVA of the memory data revealed no main effect of instruction group on percent error, $F(1,30) = 1.00$, $p > .05$, or on reaction time $F(1,30) = 1.61$, $p > .05$. This lack of an instruction group effect in memory performance

SOURCE	SS	F	P
INSTRUCTION GROUP (GROUP)	1635.2	0.05	
MEMORY LOAD (MEM)	24161	11.56	**
LINE JUDGEMENT DIFFICULTY (LINE)	487465	164.58	**
DELAY	980.5	0.36	
GROUP X MEM	12502	5.98	**
GROUP X LINE	43.1	0.01	
GROUP X DELAY	851.9	0.31	
MEM X LINE	372.97	0.43	
MEM X DELAY	2506.2	1.83	
LINE X DELAY	1822	1.47	
GROUP X LINE X MEM	7689	8.85	**
GROUP X MEM X DELAY	53.5	0.04	
GROUP X LINE X DELAY	481.2	0.39	
MEM X LINE X DELAY	91.4	0.08	
GROUP X MEM X LINE X DELAY	8.63	0.01	

(degrees of freedom = 1,30)
(* p < .05; ** p < .01)

TABLE 2. SUMMARY OF DUAL TASK LINE JUDGEMENT ANOVA

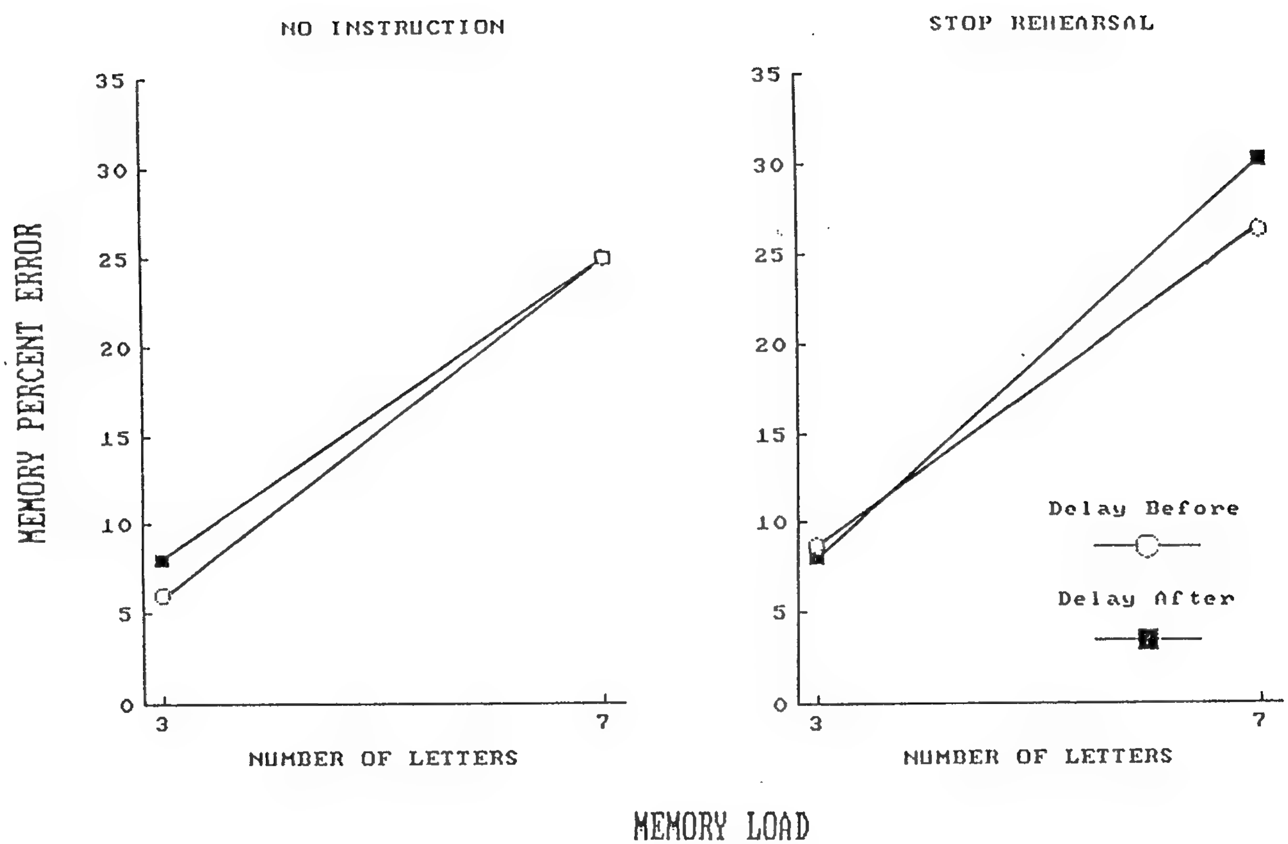

Figure 2. Dual task memory percent error as a function of instruction group, delay, and memory load.

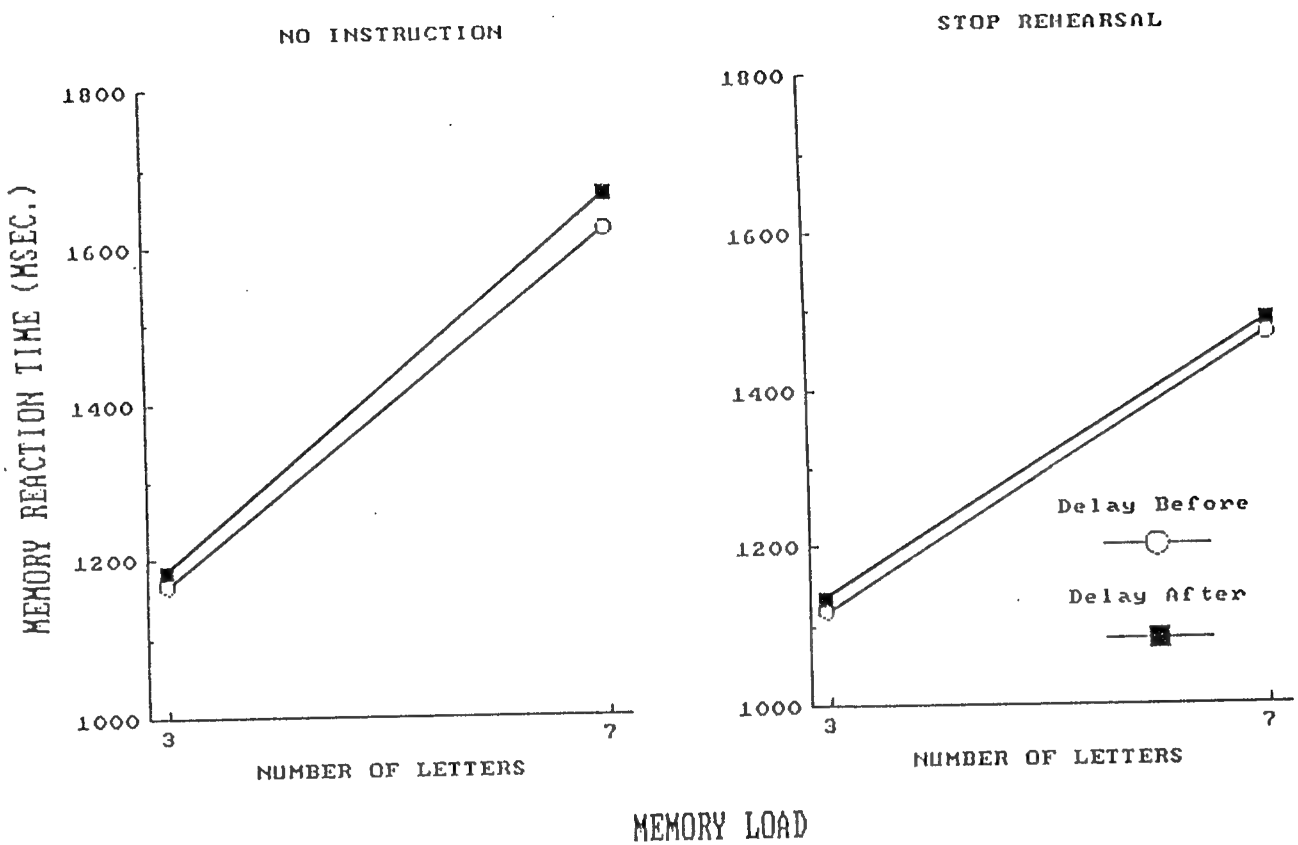

Figure 3. Dual task memory reaction time as a function of instruction group, delay, and memory load.

is evident from inspection of figures 2 and 3. Therefore, the differences found between the two groups in the line judgement task can not be readily attributed to to differences in memory task performance. A main effect of memory load was found for both percent error, $F(1,30) = 102.17$, $p < .0001$, and reaction time, $F(1,30) = 177.97$, $p < .0001$, indicating that the two difficulty manipulations of this task resulted in different levels of performance.

Inspection of Figures 2 and 3 indicates that reaction time in the seven letter condition was slower and that there were more errors in this condition relative to the three letter condition which is consistent with the expectations of the effect of memory load.

The ANOVA of both memory error and reaction time revealed no main effects of delay, $F(1,30)) < 1$, respectively. The memory analyses also failed to show an effect of line judgement difficulty on memory percent error or reaction time, $F(1,30) < 1$. However, a memory load x line judgement difficulty x delay interaction was found for memory reaction time, $F(1,30) = 4.63$, $p < .04$. This three way interaction, illustrated in Figure 4, was further examined in two separate 2-way ANOVAs, one for each level of memory load. Line judgement difficulty and delay were the independent variables in each ANOVA. As illustrated in Figure 4, the delay x line judgement difficulty interaction appears to be located in the seven letter condition

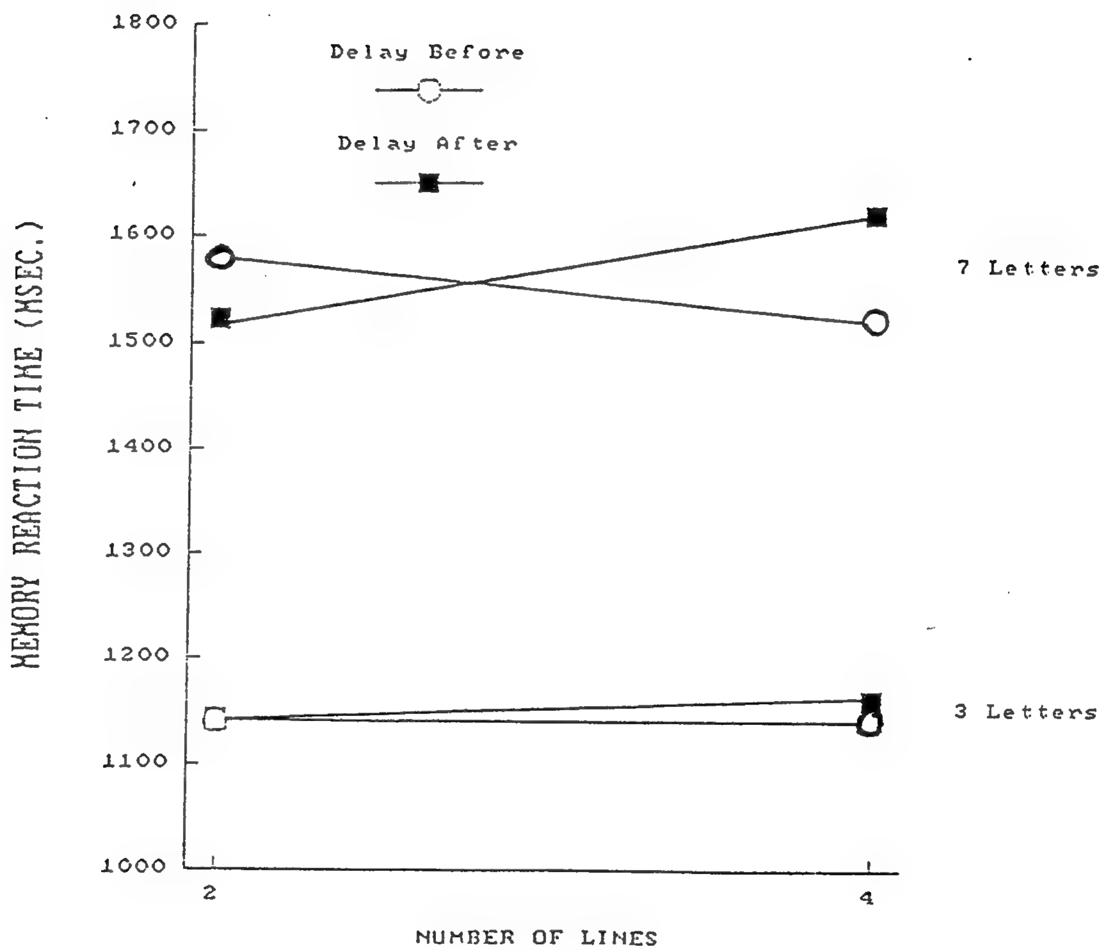

Figure 4. Dual task memory reaction time as a function of delay, memory load, line judgement difficulty.

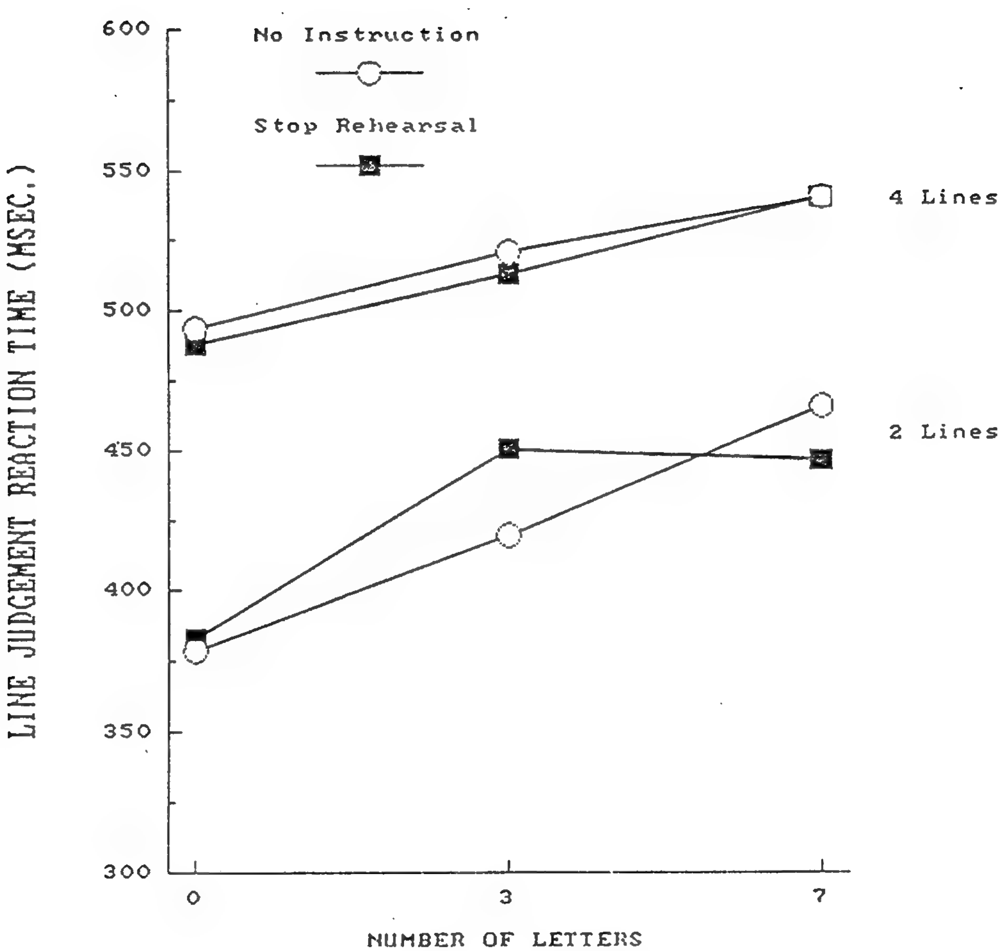

Figure 5. Line judgement reaction time as a function of instruction group, memory load, and line judgement difficulty.

only.

The analysis of the seven letter condition revealed no effect of line judgement difficulty, $F(1,30) < 1$. However the analysis revealed a lines x delay interaction, $F(1,30) = 11.02$, $p < .002$. A line x delay interaction was not found for the three letter memory condition, $F(1,30) < 1$. It is apparent from Figure 4 that the delay after condition with a memory load of seven letters resulted in a difference in memory reaction time between the two and four line judgement conditions. This increment in memory reaction time does not exist in the three letter memory conditions. A post-hoc t test for correlated samples showed that the difference between two and four lines with a memory load of seven letters was significant for the delay after condition, $t(30) = 2.33$, $p < .01$. However, the difference between two and four lines in the delay before condition under a memory load of seven letters was insignificant, $t(30) = 1.87$, $p > .05$. Therefore, it appears that increases in the difficulty of the line judgement task did cause some increase in memory reaction time in the seven letter task for the delay after condition. This condition was expected to be most sensitive to any effects of line judgement difficulty on the memory task, and indicates some inability of subjects to adhere to memory task emphasis instructions under this condition. Since no group factor was involved in the interaction, this finding suggests that

the necessity to interrupt rehearsal of the seven letter task to make the line judgement had an adverse effect on memory reaction time for each group in the delay after condition.

No other significant interactions were found in the memory dual task reaction time and percent error analysis. A complete summary of the memory analyses is provided in Tables 3 and 4.

Single vs. Dual Task Analyses

Line judgement task: Differences in line judgement reaction times between the single task condition and the two dual task conditions (memory loads 3 and 7) are displayed in Figure 5 as a function of instruction group. A three-way ANOVA was conducted on the data displayed in Figure 5. The variables in the ANOVA were instruction group, (stop rehearsal and no instruction), memory load, (zero,three, and seven letters), and line judgement difficulty, (2 and 4 lines). The results of the ANOVA are summarized in Table 5. The analysis revealed a main effect of memory load, $F(2,60) = 29.57$, $p < .0001$. A post-hoc Newman Keuls test indicated that the single task line judgement condition (zero memory load) had the fastest overall reaction times followed by the three and seven letter loads respectively, which were significantly

SOURCE	SS	F	P
INSTRUCTION GROUP (GROUP)	319.5	1	
MEMORY LOAD (MEM)	23104	102.17	**
LINE JUDGEMENT DIFFICULTY (LINE)	1.56	0.02	
DELAY	92.6	0.95	
GROUP X MEM	61.1	0.3	
GROUP X LINE	95.1	0.94	
GROUP X DELAY	11.4	0.12	
MEM X LINE	21.4	0.24	
MEM X DELAY	12.3	0.14	
LINE X DELAY	25	0.31	
GROUP X LINE X MEM	40.6	0.45	
GROUP X MEM X DELAY	217.6	2.76	
GROUP X LINE X DELAY	30.3	0.38	
MEM X LINE X DELAY	92.6	1.28	
GROUP X MEM X LINE X DELAY	15	0.21	

(degrees of freedom = 1,30)
(* $p<.05$; ** $p<.01$)

TABLE 3. SUMMARY OF DUAL TASK MEMORY PERCENT ERROR ANOVA

SOURCE	SS	F	P
INSTRUCTION GROUP (GROUP)	726010	1.61	
MEMORY LOAD (MEM)	10794920	177.97	**
LINE JUDGEMENT DIFFICULTY (LINE)	15329	0.53	
DELAY	36744	0.81	
GROUP X MEM	218947	3.6	
GROUP X LINE	9937	0.34	
GROUP X DELAY	3031	0.07	
MEM X LINE	449	0.08	
MEM X DELAY	4168	0.19	
LINE X DELAY	165496	9.51	**
GROUP X LINE X MEM	1487	0.08	
GROUP X MEM X DELAY	2444	0.11	
GROUP X LINE X DELAY	22107	1.27	
MEM X LINE X DELAY	7494	4.63	*
GROUP X MEM X LINE X DELAY	7320	0.45	

(degrees of freedom = 1,30)
(* $p<.05$; ** $p<.01$)

TABLE 4. SUMMARY OF DUAL TASK MEMORY REACTION TIME ANOVA

different from one another. Therefore, a significant single to dual task decrement existed in the line judgement task. This finding is consistent with the overall effect of memory load on line judgement reaction time discussed previously.

The single vs. dual line judgement analysis failed to show an instruction group effect, $F(1,30) < 1$, or an instruction group x memory load interaction, $F(2,60) = 1.24$, $p > .05$ Therefore, the decrement from single to dual task trials was the same for the stop rehearsal and no instruction group.

As displayed in Figure 5, there appears to be a difference in line judgement reaction time in the two line condition at a memory load of three letters between the two instruction groups. If this difference is significant, an alternative explanation for the lack of any further decrement in the two line judgement task in the stop rehearsal group could be that the two line task was also data limited. This would weaken the argument that is critical to the present hypothesis which states that the two groups displayed differences in concurrent line judgement performance as a result of different rehearsal instructions. This apparent difference in the two line condition was investigated by conducting a t-test which compared the mean reaction time of each group to the two line task with a memory load of three letters. The t-test

SOURCE	df	SS	F	P
INSTRUCTION GROUP (GROUP)	1	22.75	0.01	
LINE JUDGEMENT DIFF. (LINE)	1	626167	149.5	**
MEMORY LOAD (MEM)	2	167797	28.89	**
MEM X LINE	2	9780	3.08	*
GROUP X MEM	1	7143	1.23	
GROUP X LINE	1	2091	0.5	
GROUP X LINE X MEM	2	8142	1.56	

(* p<.05; ** p<.01)
* Delay variable omitted from ANOVA
since single task trials were included

TABLE 5. SINGLE VS. DUAL TASK LINE JUDGEMENT REACTION TIME ANOVA

revealed that this difference in the two line task between the two instruction groups was not significant $t(30) = 1.54$, $p > .05$.

The analysis also revealed a main effect of line judgement difficulty, $F(1,30) = 149.50$, $p < .0001$, as well as a line judgement difficulty x memory load interaction, $F(2,60) = 3.08$, $p < .05$. This interaction depicted in Figure 6, appears to be attributable to a greater initial decrement from single to dual task line judgement performance in the two line versus the four line condition. In order to investigate this apparent difference in the initial single to dual task decrement, a two-way ANOVA was conducted on the single task and three letter memory load line judgement data. The variables in the ANOVA were memory load (zero and three) and line judgement difficulty (two and four lines). The critical aspect of this ANOVA is the memory load x line judgement difficulty interaction. If this interaction is significant, then it would indicate that the initial decrement in line judgement reaction time is not equal for each level of line judgement difficulty. The analysis revealed a main effect of lines, $F(1,30) = 159.84$, $p < .0001$ and a memory load x line judgement difficulty interaction, $F(1,30) = 4.73$, $p < .05$.

Therefore, the initial decrement in line judgement reaction time from single task (zero memory load) to a memory load of three letters is not equivalent for each

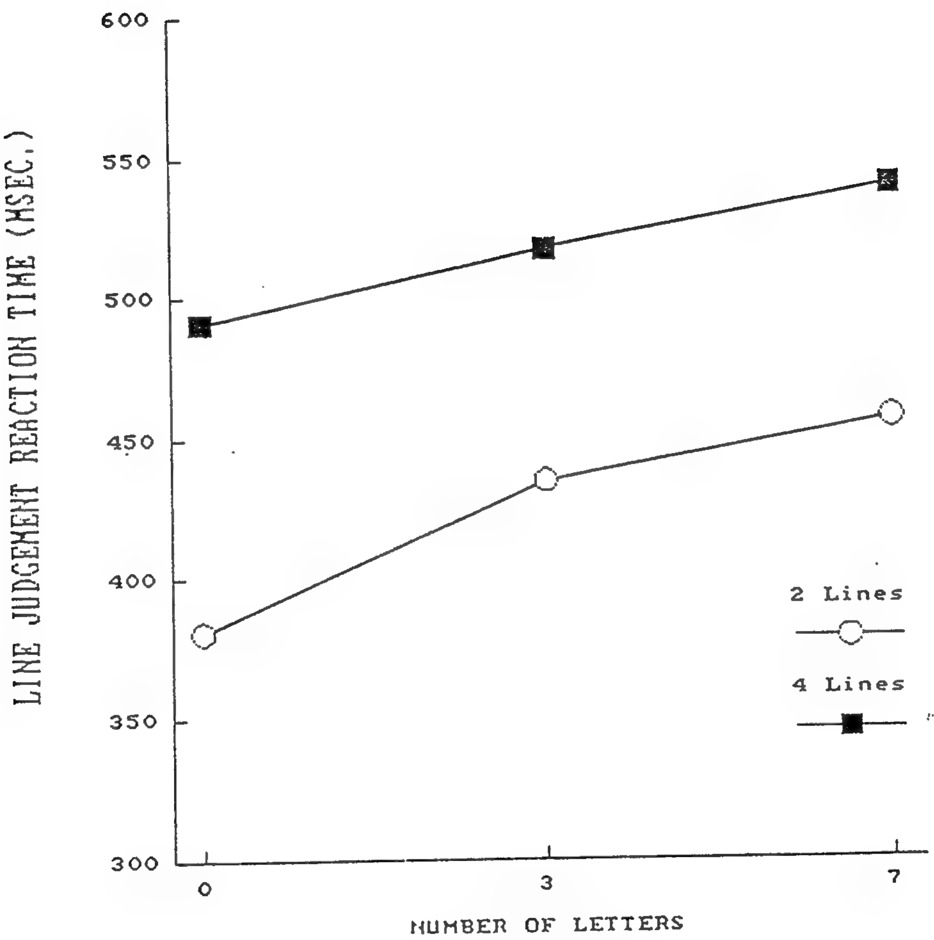

Figure 6. Line judgement reaction time as a function of line judgement difficulty and memory load.

level of line judgement difficulty, as Figure 6 indicates. A post-hoc t-test was conducted on each level of line judgement difficulty to determine if the initial decrement was greater for two or four lines. The t-test conducted on the two line condition revealed that the difference between the single task and three letter memory load line judgement data was significant, $t(15) = 6.16$, $p < .001$. The t-test conducted on four line condition also revealed a significant difference between the single task and three letter memory load conditions $t(15) = 2.45$, $p < .02$. Therefore, the magnitude of the initial decrement in line judgement reaction time from single to dual task conditions was greater in the two line condition than in the four line condition. This finding also lends additional support to the interpretation that the two line judgement task was more sensitive to memory demands than the four line task.

Memory task: Two three-way single vs. dual task ANOVA's were conducted on the memory reaction time and percent error data. The variables in each ANOVA were instruction group (stop rehearsal and no instruction) and line judgement difficulty, (zero, two, and four lines), and memory load (3 and 7 letters).

The single vs. dual task memory data are displayed in Figures 7 and 8. Complete summaries of the memory percent error and reaction time ANOVAs are provided in Tables 6 and 7. The

analysis revealed no effects of line judgement difficulty on either memory reaction time and percent error, $F(2,60) = .25$, $p < .74$ and $F(2,60) = .13$, $p < .87$, respectively. This lack of a difference between single and dual task conditions is obvious from inspection of Figures 7 and 8. The effect of group was also insignificant for both reaction time and percent error, $F(1,30) = 1.78$, $p > .05$ and $F(1,30) < 1$ respectively. These results suggest that subjects in both instruction groups followed the instructions to emphasize memory performance during dual task trials.

The analysis also revealed a main effect of memory load for both the reaction time and percent error data, $F(1,30) = 201.26$, $p < .0001$ and $F(1,30) = 143.18$, $p < .0001$ respectively. No interactions involving memory load reached significance, indicating that the lack of a single to dual memory decrement was equivalent for each level of memory task difficulty.

The ANOVA of both the percent error and reaction time data showed an insignificant instruction group x line judgement difficulty interaction, $F(2,60) < 1$ indicating no differences between single and dual task memory performance as a function of instruction group. However, the instruction group x line judgement difficulty interaction in the reaction time data, nearly reached significance, $F(2,60) = 2.54$, $p > .05$. As displayed in Figure 8, the no instruction group was slower than the stop rehearsal group in response to the memory task in all

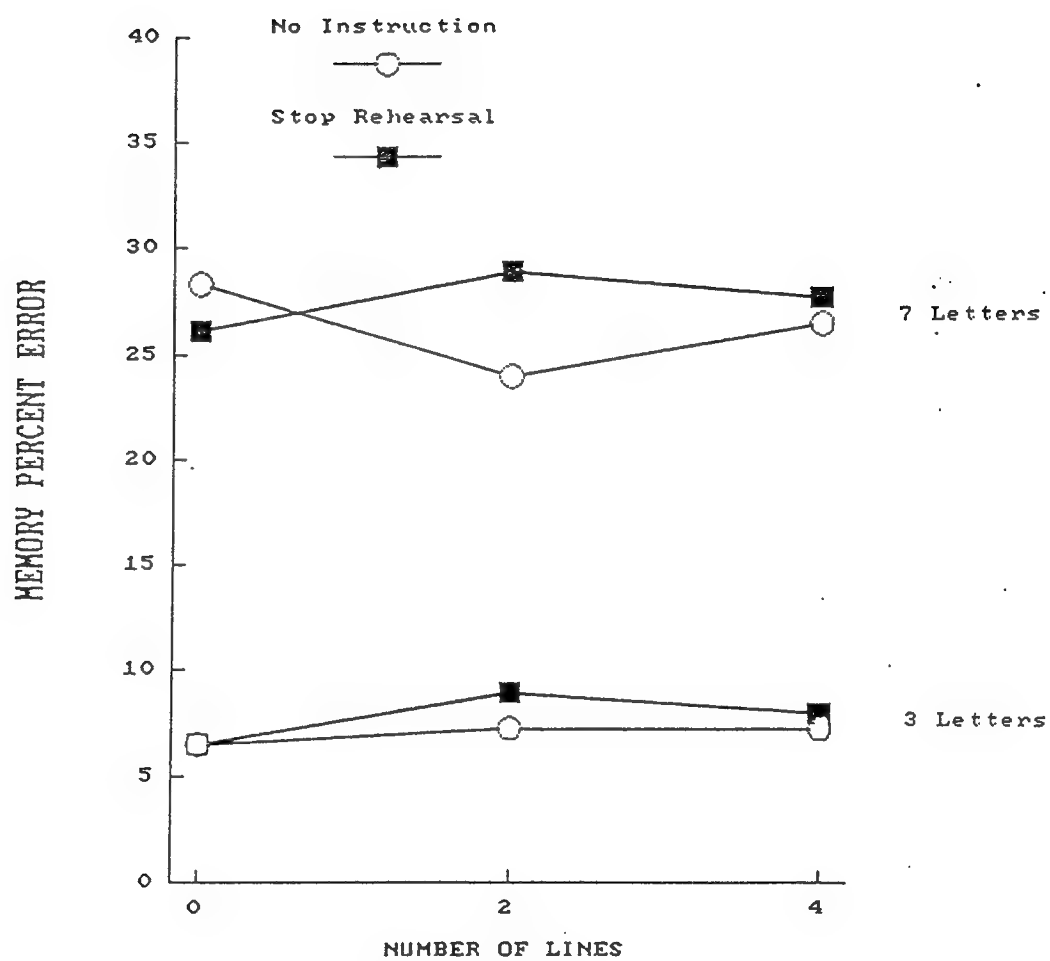

Figure 7. Memory percent error as a function of line judgement difficulty, instruction group, and memory load.

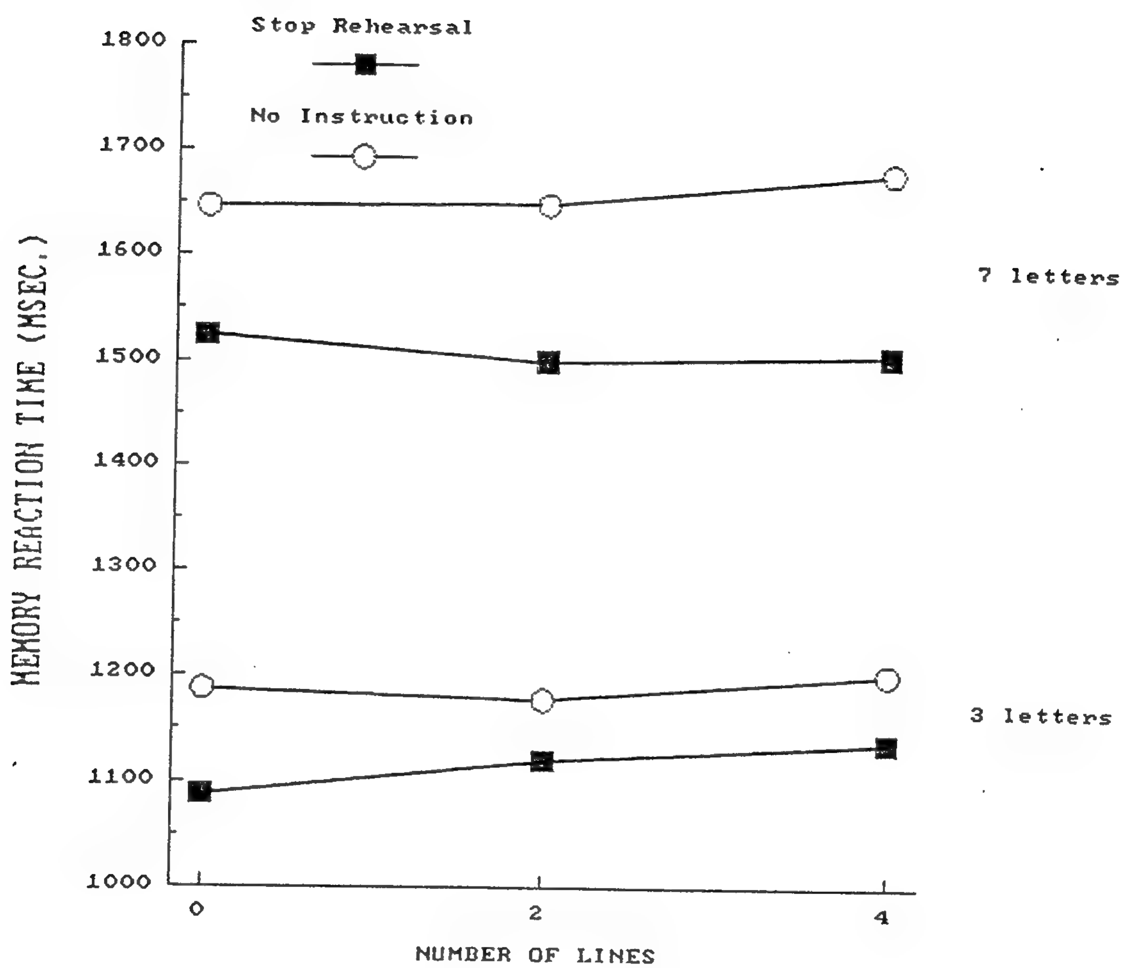

Figure 8. Memory reaction time as a function of instruction group, memory load, and line judgement difficulty.

SOURCE	df	SS	F	P
INSTRUCTION GROUP (GROUP)	1	107.35	0.23	
MEMORY LOAD (MEM)	2	36692	143.18	**
LINE JUDGEMENT DIFF. (LINE)	1	19	0.13	
MEM X LINE	2	92.27	0.5	
GROUP X MEM	2	20.30	0.08	
GROUP X LINE	1	361.40	2.54	
GROUP X LINE X MEM	2	103	0.68	

(* p<.05; ** p<.01)
* Delay variable omitted from ANOVA
since single task trials were included

TABLE 6. SINGLE VS. DUAL TASK MEMORY PERCENT ERROR ANOVA

SOURCE	df	SS	F	P
INSTRUCTION GROUP (GROUP)	1	1116663	1.72	
MEMORY LOAD (MEM)	2	17029972	201.26	**
LINE JUDGEMENT DIFF. (LINE)	1	17114	0.25	
MEM X LINE	2	22868	0.58	
GROUP X MEM	2	152142	1.80	
GROUP X LINE	1	10719	0.16	
GROUP X LINE X MEM	2	120645	1.63	

(* p<.05; ** p<.01)
* Delay variable omitted from ANOVA
since single task trials were included

TABLE 7. SINGLE VS. DUAL TASK MEMORY REACTION TIME ANOVA

line judgement conditions.

DISCUSSION

The main purpose of the present study was to re-examine previous evidence which lends support to the Wickens (1980,1984) hypothesis that perceptual encoding and central processing functions depend on a common resource.

Two findings that are critical to an alternate hypothesis which views central processing as being composed of two distinct functions, working and span memory, only the former sharing a common resource with perceptual encoding were provided by the present results. First, perceptual line judgement reaction time in the two-line condition increased as memory demands increased only for the group given no instructions to stop rehearsal of the memory task. This finding is a replication of previous results reported by Shulman et al. (1971) and Shulman and Greenberg (1971). However, the same letter memory task failed to interfere with line judgement performance for the group given specific instructions to stop rehearsing the memory items prior to presentation of the line judgement task. This result is consistent with those reported by Klapp et al. (1983), and suggests that terminating the rehearsal of items in short term memory eliminates the competition for resources responsible for the interference

between the line judgement and memory tasks observed in the no instruction group.

Secondly, memory performance was equivalent for the stop rehearsal and no instruction groups for both single and dual task conditions. The lack of an instruction group difference in memory performance suggests that the superiority of the stop rehearsal group in line judgement performance under increased memory loads cannot easily be attributed to a performance tradeoff, where memory performance is sacrificed to improve line judgement speed. It can also be maintained that the task still requires central processing capacity since the letters are temporarily stored for future recall. Therefore, equivalent memory performance in both instruction groups suggests that the differences in dual task line judgement performance between the groups can be interpreted in terms of the degree of competition for perceptual resources. In the present study, a single resource may be devoted to active processing represented here by memory rehearsal and perceptual line judgement. This interpretation taken alone supports the Wickens perceptual encoding/central processing commonality assumption. However, the present results showed that line judgement performance was unaffected by further increases in memory load when subjects were

instructed to stop rehearsing the memory items prior to responding to the line judgement task. This suggests that central processing may be composed of an active processing component and a retention or storage component, each relying on a separate resource. According to this alternate framework, perceptual encoding shares a common resource with the active processing component of central processing, whereas the retention component, span memory, relies on a separate resource. This is distinct from the Wickens framework which views central processing as a unitary capacity that draws resources from a pool also tapped by perceptual encoding.

Another variable of interest was the locus of the delay, before or after, in relation to the line judgement task. Klapp et al. (1983) reported that increases in memory difficulty slowed reaction time to the embedded task in the delay after condition only, where no delay prior to the embedded task was provided. In the Klapp et al. delay before condition increases in memory failed to affect the reaction time to the embedded task. The lack of an effect of delay on line judgement performance in the present study could be attributed to the fact that in each delay condition a two second delay before the line judgement task was always provided. Whereas, the delay after condition in the Klapp et al. study included no time interval between memory task offset and embedded task

onset. Therefore, the presence of a delay before the line judgement task in all dual task conditions in the present experiment may have hidden any effect of delay.

The absence of a delay effect in the no instruction group is not as easily reconciled, since Shulman et al. (1971) reported a main effect of delay on line judgement reaction time. In the Shulman et al. study delays of 2,5,and 8 seconds were used and always occured before the line judgement task. The two delay conditions utilized by Shulman et al. that are the most comparable with those utilized in the present experiment are the delays of 2 and 8 seconds, since delays of 2 seconds (delay after) and 7 seconds (delay before) were provided prior to line judgement task presentation. Inspection of the Shulman et al. results reveals a 4 msec. difference in line judgement reaction time between the delay conditions of 2 and 8 seconds at a memory load of three letters. This difference at a memory load of six letters is 23 msec. with longer reaction times occuring under the two second delay condition.

Examination of the present results in the two line task revealed a 6 msec. difference between the two delay conditions at memory load of three letters. At memory load of seven letters this difference was 14 msec., with longer reaction times occuring in the two second delay before (delay-after) condition. Therefore, the trend of the

present results in the two line judgement task is consistent with the Shulman et al. results. Although the present study failed to show an effect of delay in the no instruction group or any interactions involving delay, it is possible that with an increased number of subjects and an additional level of delay an effect may have been obtained.

In the present study, line judgement reaction time increased as a function of memory load only in the two line condition in the no instruction group. The lack of an effect of memory load on line judgement reaction time in the four line condition in the no instruction group is not consistent with the proposed modification to the Wickens framework. It was expected that increases in perceptual line judgement difficulty would result in greater competition for perceptual resources between the memory task and the four line judgement task. This increased competition for resources, according to the suggested modification should be greater in the no instruction group than in the stop rehearsal group, since subjects are actively rehearsing the memory items when the line judgement task is presented. The finding that an effect of memory load on the four line judgement task did not exist in either instruction group could have possibly been due to some ceiling effect in the dual task condition. In other words, the processing resources required of the four line

judgement task might have placed it in a data-limited region when combined with any memory load. In this region differences in resource investment do not affect task performance. Performance on the four line judgement task therefore may have become insensitive to further increases in memory difficulty. In addition the finding of a greater initial decrement from single to dual task trials in the two line judgement condition as compared to the four line condition futher supports the notion that the four line task may have been data limited.

The lack of a significant difference between single and dual task memory performance in the critical two line condition indicates that each group followed instructions to emphasize the letter task and is consistent with the Klapp et al.(1983) results. This finding is critical to the present hypothesis since it indicates that memory performance was unaffected by the presence of the line judgement task and permits straightforward interpretation of the line judgement data as the primary indicant of the degree of any resource competition between the two tasks.

The memory dual task analysis also revealed a trend toward slower reacton times in the no instruction group at a memory load of seven letters. One plausible interpretation to account for this trend is that the process of rehearsal in the no instruction group may have slightly interfered with the response to the memory probe.

Memory percent error was equivalent for both groups at a load of seven letters. Therefore, it is possible that the no instruction group tended toward longer memory probe response times because upon probe presentation this group performed rehearsal before responding. This argument is also consistent with the general interpretation of the line judgement data, where rehearsal of the letters in memory causes line judgement speed to be slower relative to the stop rehearsal group.

In summary, the present results support a resource framework that indicates that modifications may be necessary to elements of the multiple resources framework proposed by Wickens (1980,1984). In the Wickens framework all central processing and perceptual encoding functions are conceptualized as drawing on a unitary resource. The modification suggested by the present results posits that the perceptual/central processing distinction may not be as critical as that between active processing of information and retention and further indicates that these functions may draw on separate resources.

Since the present study provides only initial support for this suggested modification, future research should address some of its assumptions as well as the procedures used to examine resource competition. For example, a demonstration that the letter memory task used in the present research does in fact place demands on central

processing when subjects are instructed to stop rehearsal would strengthen the current proposal. A study similar to those reported by Klapp and Philipoff (1983) and Klapp et al. where a task requiring ordered recall is embedded in the retention interval of another memory task should be conducted to demonstrate that retention resources are utilized even under stop rehearsal instructions. The purpose of substituting a memory task involving ordered recall for the embedded line judgement task recall is to attempt to show that regardless of instructions about rehearsal, a task that clearly demands retention of information will interfere with the letter memory task. If it can be demonstrated that interference occurs between the two memory tasks even under instructions to stop rehearsal before embedded task presentation, more support is provided to the assumption that the letter memory task requires retention capacity under stop rehearsal instructions. If the letter memory task does not utilize such resources once rehearsal is ceased, a concurrently performed memory task would not be expected to cause dual task interference.

Both Klapp et al.(1983) and Klapp and Philipoff (1983) demonstrated that concurrent performance of a task requiring the immediate recall of ordered information embedded within the retention interval of a memory task resulted in dual task interference. These authors also demonstrated that little or no mutual interference occured

between two concurrently performed memory tasks under stop rehearsal instructions when the embedded task did not require ordered recall. The above results further support the notion that short term memory may be composed of at least two systems. Therefore, it is plausible that interference between the letter memory task used in the present experiment and an embedded memory task will occur only when the embedded task requires immediate ordered recall. This assumption could be verified in a follow up study which requires one group of subjects to perform an ordered recall task and a second group to perform a memory task that does not involve recall of ordered information during the retention interval of the letter memory task used in the present study.

Future research could also be aimed at investigating the extent to which the proposed modification to the Wickens framework is consistent with other assumptions of the Wickens multidimensional model. More specifically, the codes of processing dimension of the Wickens framework, which views verbally coded functions as relying on a separate resource than spatially coded tasks, could be addressed in a dual task paradigm. The present results showed that the active processing of a verbal memory task interfered with the processing of an embedded spatial task (line judgement). This finding appears inconsistent with the notion that verbally coded tasks rely on a resource not

shared by spatially coded tasks. Perhaps the distinction between a verbal resource and a spatial resource is relevant only to timesharing situations in which both tasks are carried out at a common stage of processing. This could be investigated in a series of dual task studies , similar to those reported by Wickens, Sandry, and Vidulich (1983), where various timesharing combinations of tasks are examined using the stop rehearsal procedure.

APPENDIX A

INTRODUCTION

As noted in the method section, a 750 msec. delay followed the offset of the warning cue which preceded the line judgement task in the stop rehearsal group. No delay prior to line judgement presentation was provided in the no instruction group. Since the analysis of the dual task line judgement reaction times revealed no effect of delay (before or after line judgement task), it was considered unlikely that the absence of an additional 750 msec. delay in the no instruction group could have contributed to the elevated reaction times obtained in this group relative to the stop rehearsal group. A follow-up study was conducted to test this assumption. The study was designed so that line judgement reaction time in the no instruction group could be investigated under a no delay and a 750 msec. delay before line judgement task condition. This was achieved by having a group of new subjects perform the no instruction group delay-after task condition under both a 750 msec. delay and no delay condition.

METHOD

Subjects: Eight females and eight males served as subjects in this experiment. Sixteen subjects were chosen to match the number of subjects in the no instruction group of the original experiment. Subjects were Wright State University students who received extra credit in their introductory psychology courses for participation.

Apparatus: All apparatus used was identical to that described in the method section of the first experiment.

Procedure: The experiment utilized a within subjects repeated measures design. Subjects performed four dual task conditions: the two difficulty levels of the memory task (3 and 7 letters performed concurrently with the two line judgement task) with a 750 msec. delay or no delay occuring prior to line judgement task presentation. The procedure followed that outlined previously for the no instruction group delay-after line judgement condition. The delay-after condition was selected, since the relative increase in the delay prior to the line judgement task caused by an additional 750 msec. delay was greater for this condition than in the delay-before condition.

Therefore, any effect of an additional delay on line judgement reaction time should be observed in this condition. Only the two line judgement task was timeshared with the letter memory task, since the four line judgement task was unaffected by increases in memory demand or instructions regarding rehearsal in the first experiment.

Each subject performed ten practice trials of each single task condition (3 letter memory, 7 letter memory, 2 line judgement) and dual task condition (each level of memory load performed concurrently with the line judgement task with a 750 msec. delay or no delay preceding line judgement task presentation). During data collection, each subject performed twelve trials of the four dual task conditions. Therefore, the amount of practice and data collection trials performed per condition by each subject was the same as in the original experiment.

In order to eliminate the possibility of any order effects, one half of the subjects practiced under one delay condition first and then performed the data collection trials under that same condition before performing the second delay condition. The other half of the subjects practiced and tested under the other delay condition first before performing the second delay condition.

RESULTS

A two-way analysis of variance (ANOVA) was conducted on the mean line judgement reaction times under each condition. The variables in the ANOVA were memory load (3 and 7 letters) and delay (zero delay and 750 msec. delay). The line judgement reaction times analyzed in the ANOVA are displayed in Figure 9 as a function of memory load and delay condition. The ANOVA revealed no significant effect of delay on line judgement reaction time $F\ (1,15) = 3.34$, $p < .1$, indicating that the presence or absence of a 750 msec. prior to line judgement task presentation had no differential effect on reaction time to the task. The means obtained under each delay condition were 397 msec. for the delay condition and 403 msec. for the no delay condition. The ANOVA failed to reveal a significant memory load x delay interaction, $F\ (1,15) = .02$, $p < .9$, indicating the absence of a delay effect at each level of memory task difficulty.

The analysis also revealed a significant effect of memory load on line judgement reaction time $F\ (1,15) = 12.95$, $p < .01$. This effect is illustrated in Figure 9. The replication of an effect of memory load on line judgement reaction time lends further support to the notion that active rehearsal of memory items interferes with

perceptual line judgement processing.

Separate two-way ANOVAs conducted on the memory reaction time and memory percent error data revealed significant main effects of memory load, $F(1,15) = 49.1$, $p < .001$, and $F(1,15) = 34.01$, $p < .001$, with larger performance decrements occuring in the seven letter memory task. This finding is also consistent with the results of the first experiment. The memory analyses also revealed no effect of delay on either memory reaction time or percent error, $F(1,15) = .47$, $p < .5$. and $F(1,15) = 1.77$, $p < .20$. The memory load x delay interaction was also insignificant for both memory reaction time and percent error, $F(1,15) = .01$, $p < .9$, and $F(1,15) = 3.09$, $p < .1$, respectively. Both the memory task reaction time and percent error data are displayed in Table 8.

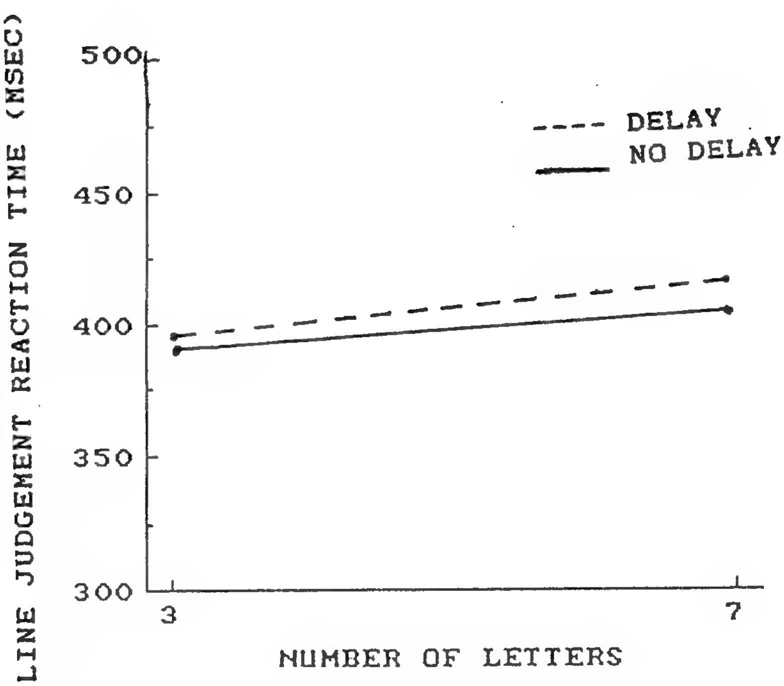

Figure 9. Line judgement reaction time as a function of delay following offset of warning cue.

MEMORY LOAD	DELAY	
	NO DELAY	750 msec.
3 LETTERS	1160 6.8	1130 8.8
7 LETTERS	1663 30.1	1628 21.4

TABLE 8. Memory task reaction time and percent error as a function of memory load and delay.

APPENDIX B

General Instructions

During this experiment you will perform two tasks. One involves remembering a list or string of letters that will appear one letter at a time on the screen in front of you. The other task involves looking at a number of vertical lines on the screen and judging which line is the longest. In some instances you will perform each task alone, and on others you will perform a combination of the two. Any questions?

We will also pay you for your participation in this experiment at a rate of $4.00 per hour or each part of an hour. The experiment will take approximately 3 hours to complete. You will be given several breaks during this time.

Before we begin, I would like you to read this form, sign, and date it if you agree to participate in this experiment.

Stop Rehearsal Group

Single Task Trials

Memory Instructions

During this task you will be given a list or string of letters to remember. The number of letters in each string will change from time to time. Each letter string will be shown on the screen in front of you one letter at a time. Before each string is shown, you will hear a tone and see an asterisk appear in the center of the screen. This is to signal you that the trial is about to begin. It is important to pay attention to the center of the screen as soon as the signals appear, since each list will follow immediately. I would like you to study each list, concentrating on the order in which each letter appears. After the last letter of the string is shown, the screen will go blank

for a brief period of time. During this brief period you should silently rehearse or repeat to yourself the letters you just saw in the same order that they appeared on the screen. Try to complete this rehearsal as rapidly as possible to ensure that you repeat the list to yourself at least once and more often if you have the time. At the end of this blank period, you will see the words "STOP REHEARSAL" appear on the screen. This is your signal to immediately stop rehearsing the letters and get ready for the pair of test letters. It is <u>very important</u> that you STOP rehearsing the letters as soon as this signal appears. The test letter pair will appear next to one another vertically (e.g. A).

B

You are to decide as quickly as possible whether or not these two letters appeared in the order shown in the list you just finished reading and push the appropriate button on the keypad. For example if you were presented the letter string "A,B,C,D" and then were shown the two letters D, you would respond by pressing the button labeled "N" to

C

signify that D did <u>not</u> appear in that order in the original list.

C

On the other hand, if you were shown the letters C after reading the

D

same list, you would respond by pressing the button labeled "Y" to signify that the letters did appear in this order in the original list. Any questions?

Please use only one hand to make your responses. If you are right-handed, make a "yes" response with your right index finger and a

"no" response with your right middle finger. If you are left-handed, use your middle finger for a "yes" response and your index finger for a "no" response. The number of letters in each list will vary but you will always be shown just two letters to base your judgements on.

Again, please respond as quickly as possible after you have determined whether the two letters appeared in the same order in the original letter list. Also, remember that it is critical that you immediately stop rehearsing the letter list when the "STOP REHEARSAL" message appears on the screen.

After making your response, please keep your attention on the screen to wait the next trial, since you will see several strings without a break in between. Again, the tone and asterisk will be used to signal the start of each new list. I will tell you after the last list that the trial is over and you can than relax.

Here is the first trial. Again study each list carefully and be sure to concentrate on remembering the order of each list. Also be sure to stop rehearsing the letters as soon as the signal to do so appears.

Line Judgement Instructions

During this task you will be shown a set of vertical lines and will have to decide which line is the longest. The lines will be presented on the screen in front of you and will remain visible until you make your response. On some trials you will see only two lines and on other trials you may be shown three or four lines. In either case, decide as quickly as possible which line is longest, and make your response. You are always to make your response by pressing the button on the keypad that corresponds with the longest line on the screen. The buttons are labeled 1,2,3,4 from left to right. All four fingers of your preferred hand should be rested on the buttons throughout all trials. Therefore when a trial consists of only two lines, you would use the first two buttons on the keypad only and press them with your index and middle fingers. When a trial consists of four lines, you should again rest all of your fingers on the buttons and be prepared to use each one. I will tell you before each trial starts, how many lines will appear during that set so you can position your fingers properly. Before each set of lines appears, a row of four stars will be shown briefly in the middle of the screen. This is to signal you that the lines are about to be presented, and that they will appear in this location. It is important that you get ready to perform the task and that you concentrate your attention on the location of the stars so that you can make your judgement about length as quickly as possible. Always remember to concentrate on the area where the stars appear because this will help you to perform as best as possible. As soon as you make your responses to one set of lines the next set will appear, so be sure to pay attention to the screen until I tell you the trial is

over. Remember to make your responses as quickly as you can, while keeping your errors low. Any questions?

<u>Stop Rehearsal Group</u>

Dual Task (Delay Before)

Up to this point you have performed each task by itself. I would now like you to perform a combination of the two tasks. During these trials you will first see the letter string and after a brief period the vertical lines will appear. You should perform both of these tasks just as you did before. Make your response as quickly as possible while keeping your errors low, and then wait for the next trial to begin.

Each trial will begin with the warning signal, followed by the letter string. Again, study each letter string carefully, concentrating on the order they appeared in. After the last letter goes off the screen, the screen will go blank for a brief period. Remember to rapidly repeat or rehearse the letter string to yourself in the correct order during this period. You will then see the words "STOP REHEARSAL" in the center of the screen. Again, I want to emphasize that it is <u>very important</u> that you stop rehearsing the letters <u>as soon as</u> this signal appears. Immediately following this either two or four vertical lines will appear. In these combination trials, the STOP REHEARSAL message takes the place of the stars that were used to warn you that the line judgement task was about to begin. When you see the message, stop rehearsing the letters, and concentrate your attention on the place on the screen where the message appeared, because the lines will appear there very shortly. You should respond to these lines just as you did before by pressing the button on the keypad that corresponds to the longest line. After you make your response to the lines, you will see two letters appear just as before.

You should respond to these as you did before. If the letters were in the string you just read in the order shown, you would press the button labeled "Y". If the letters did not appear in that sequence in the string you just read, you would respond by pressing the button labeled "N".

Therefore, you will press a button on the keypad two times on each trial. Once for the line judgement task and once for the letter memory task. After you make your response to the letter task, a new trial will begin immediately. You will hear the tone and see the star before each new trial. Be sure to have your four fingers resting on the four buttons throughout all trials, so you are always ready to respond quickly. Any questions?

During these combintation trials, it is very important that you concentrate on your performance of the letter task. That is, devote more of your attention to remembering the order of the letters, and perform the line judgement task with whatever attention you have left over. We all know that sometimes we can't do two tasks or things as well as each one by itself. If that happens here, concentrate on continuing high performance of the letter task, and try to perform it as well as you do when it is by itself. Any questions?

No Instruction Group

Dual Task (Delay Before)

Up to this point in the experiment, you have performed each task by itself. I would now like you to perform a combination of the two tasks. During these trials you will first see the letter string and after a brief period the vertical lines will appear. You should perform both of these tasks just as you did before. Make your response as quickly as possible while keeping your errors low, and then wait for the next trial to begin.

Each trial will begin with the warning signal, followed by the letter string. Again, study each letter string carefully, concentrating on the order they appeared in. After the last letter goes off the screen, the screen will go blank for a brief period. Remember to rapidly repeat or rehearse the letter string to yourself in the correct order during this period. You will then see four stars appear in the center of the screen. Immediately following this either two or four vertical lines will appear where the stars had been. You should respond to these lines just as you did before by pressing the button on the keypad that corresponds with the longest line. After you make your response to the lines, you will see two letters appear just as before. You should respond to these as you did before. If the letters were in the string you just read in the order shown, you would press the button labeled "Y". If the letters did not appear in that sequence in the string you just read, you would respond by pressing the button labeled "N".

Therefore, you will press a button on the keypad two times on each trial. Once for the line judgement task and once for the letter memory

task. After you make your response to the letter task, a new trial will begin immediately. You will hear the tone and see the star before each new trial. Be sure to have your four fingers resting on the four buttons throughout all trials, so you are always ready to respond quickly. Any questions?

During these combination trials, it is very important that you concentrate your attention on your performance of the letter task. That is, devote more of your attention to remembering the order of the letter list and perform the line judgement task with whatever attention you have left over. We all known that sometimes we can't do two tasks or things as well as each one by itself. If that happens here, concentrate on continuing high performance of the letter task, and try to perform it as well as you do when it is by itself. Any questions?

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